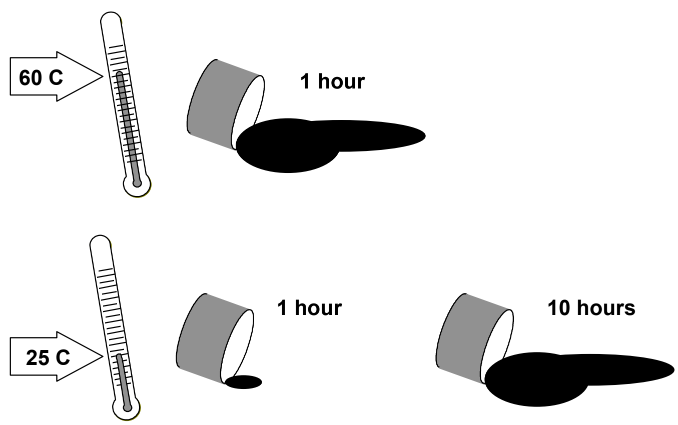
II. Improving HMA Performance with Superpave

To understand how the performance based specifications of Superpave are used to improve pavement performance requires an understanding of the characteristics of the individual materials that make up hot mix asphalt (HMA), and how they behave together as an asphalt mixture. Both the individual properties and their combination affect the pavement performance. Superpave uses these characteristics in ways that are new to the asphalt industry, as well as in ways that have been used for many years. A comparison between the old and the new helps bridge the understanding to the Superpave system.

The objectives of this session will be to describe the material properties of HMA, both of the individual components of HMA (asphalt and aggregate) and the HMA mixture itself. This description will include the tests and specifications that are used to characterize HMA materials, both prior to Superpave and under the new Superpave system. Most importantly, the session will describe how the Superpave system uses the tests and specifications to improve upon the three primary distresses in HMA pavements: permanent deformation, fatigue cracking and low temperature cracking.

HOW ASPHALT BEHAVES

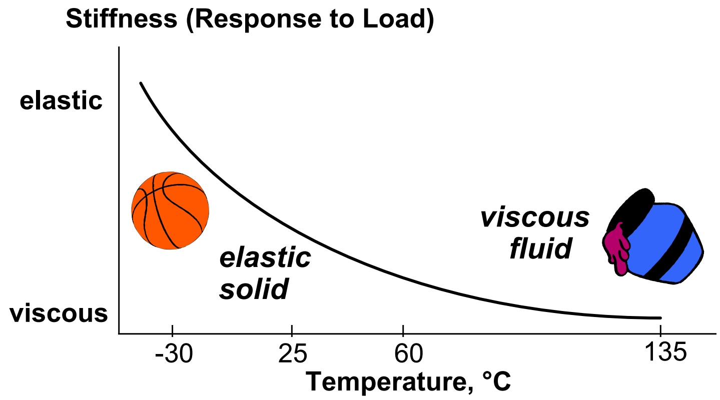
Asphalt is a *viscoelastic* material. This term means that asphalt has the properties of both a viscous material, such as motor oil, or more realistically, water, and an elastic material, such as a rubber. However, the property that asphalt exhibits, whether viscous, elastic, or most often, a combination of both, depends on *temperature* and *time of loading*. The flow behavior of an asphalt could be the same for one hour at 60°C or 10 hours at 25°C.



In other words, the effects of time and temperature are related; the behavior at high temperatures over short time periods is equivalent to what occurs at lower temperatures and longer times. This is often referred to as the time-temperature shift or superposition concept of asphalt cement.

High Temperature Behavior

In hot conditions (e.g., desert climate) or under sustained loads (e.g., slow moving trucks), asphalts cements behave like *viscous* liquids and flow. Viscosity is the material characteristic used to describe the resistance of liquids to flow.



Viscous liquids like hot asphalt are sometimes called *plastic* because once they start flowing, they do not return to their original position. This is why in hot weather, some asphalt pavements flow under repeated wheel loads and wheel path ruts form. However, rutting in asphalt pavements during hot weather is also influenced by aggregate properties and it is probably more correct to say that the asphalt *mixture* is behaving like a plastic.

Low Temperature Behavior

In cold climates (e.g., winter days) or under rapid loading (e.g., fast moving trucks), asphalt cement behaves like an *elastic* solid. Elastic solids are like rubber bands; when loaded they deform, and when unloaded, they return to their original shape. Any elastic deformation is completely recovered.

If too much load is applied, elastic solids may break. Even though asphalt is an elastic solid at low temperatures, it may become too brittle and crack when excessively loaded. This is the reason low temperature cracking sometimes occurs in asphalt pavements during cold weather. In these cases, loads are applied by internal stresses that accumulate in the pavement when it tries to shrink and is restrained (e.g., as when temperatures fall during and after a sudden cold front).

Intermediate Temperature Behavior

Most environmental conditions lie between the extreme hot and cold situations. In these climates, asphalt binders exhibit the characteristics of both viscous liquids and elastic solids. Because of this range of behavior, asphalt is an excellent adhesive material to use in paving, but an extremely complicated material to understand and explain. When heated, asphalt acts as a lubricant, allowing the aggregate to be mixed, coated, and tightly-compacted to form a smooth, dense surface. After cooling, the asphalt acts as the glue to hold the aggregate together in a solid matrix. In this finished state, the behavior of the asphalt is termed viscoelastic; it has both elastic and viscous characteristics, depending on the temperature and rate of loading.

Conceptually, this kind of response to load can be related to an automobile shock absorbing system. These systems contain a spring and a liquid filled cylinder. The spring is elastic and returns the car to the original position after hitting a bump. The viscous liquid within the cylinder dampens the force of the spring and its reaction to the bump. Any force exerted on the car causes a parallel reaction in both the spring and the cylinder. In hot mix asphalt, the spring represents the immediate elastic response of both the asphalt and the aggregate. The cylinder symbolizes the slower, viscous reaction of the asphalt, particularly in warmer temperatures. Most of the response is elastic or viscoelastic, (recoverable with time), while some of the response is plastic and non-recoverable.

Aging Behavior

Because asphalt cements are composed of organic molecules, they react with oxygen from the environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. Oxidation causes the asphalt cement to become more brittle, generating the term oxidative hardening or age hardening.

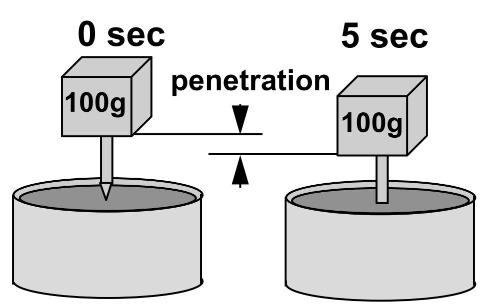
In practice, a considerable amount of oxidative hardening occurs before the asphalt is placed. At the hot mix facility, asphalt cement is added to the hot aggregate and the mixture is maintained at elevated temperatures for a period of time. Because the asphalt cement exists in thin films covering the aggregate, the oxidation reaction occurs at a much faster rate. “Short term aging” is used to describe the aging that occurs in this stage of the asphalt’s “life”.

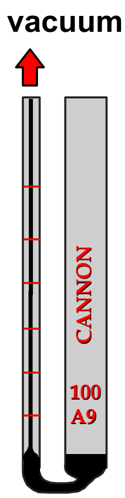
Oxidative hardening also occurs during the life of the pavement, due to exposure to air and water. “Long term aging” happens at a relatively slow rate in a pavement, although it occurs faster in warmer climates and during warmer seasons. Because of this hardening, old asphalt pavements are more susceptible to cracking. Improperly compacted asphalt pavements may exhibit premature oxidative hardening. In this case, inadequate compaction leaves a higher percentage of interconnected air voids, which allows more air to penetrate into the asphalt mixture, leading to more oxidative hardening.

Other forms of hardening include volatilization and physical hardening. Volatilization occurs during hot mixing and construction, when volatile components tend to evaporate from the asphalt. Physical hardening occurs when asphalt cements have been exposed to low temperatures for long periods. When the temperature stabilizes at a constant low value, the asphalt cement continues to shrink and harden. Physical hardening is more pronounced at temperatures less than 0°C and must be considered when testing asphalt cements at very low temperatures.

PRE-SUPERPAVE ASPHALT PROPERTY MEASUREMENTS

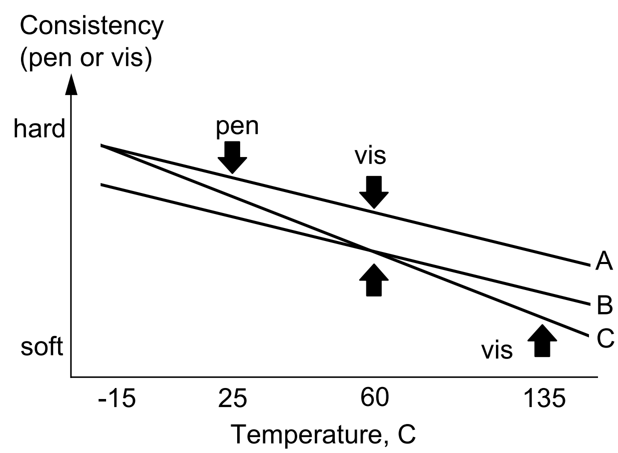
Because of its chemical complexities, asphalt specifications have been developed around physical property tests, using such tests as penetration, viscosity, and ductility. These physical property tests are performed at standard test temperatures, and the test results are used to determine if the material meets the specification criteria. However, there are limitations in what these test procedures provide. Many of these tests are empirical, meaning that field experience is required before the test results yield meaningful information. Penetration is an example of this. The penetration test represents the stiffness of the asphalt, but any relationship between asphalt penetration and performance has to be gained by experience. An additional drawback of empiricism is that the relationship between the test and performance may not be very good.





Another limitation to these tests and specifications is that the tests do not give information for the entire range of typical pavement temperatures. Although viscosity is a fundamental measure of flow, it only provides information about higher temperature viscous behavior -- the standard test temperatures are 60°C and 135°C. Lower temperature elastic behavior cannot be realistically determined from this data to completely predict performance. As well, penetration describes only the consistency at a medium temperature (25°C). No low temperature properties are directly measured in the current grading systems.

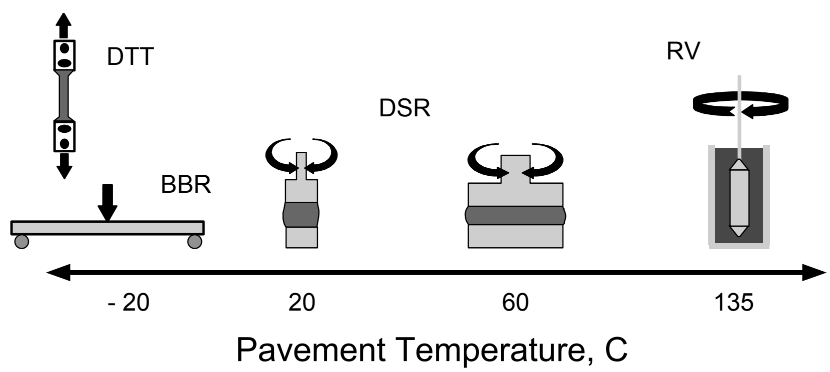
The penetration and viscosity asphalt specifications can classify different asphalts with the same grading, when in fact these asphalts may have very different temperature and performance characteristics. As an example, this figure shows three asphalts that have the same viscosity grade because they are within the specified viscosity limits at 60°C, have the minimum penetration at 25°C, and reach the minimum viscosity at 135°C. While Asphalts A and B display the same temperature dependency, they have much different consistency at all temperatures. Asphalts A and C have the same consistency at low temperatures, but remarkably different high temperature consistency. Asphalt B has the same consistency at 60°C, but shares no other similarities with Asphalt C. Because these asphalts meet the same grade specifications, one might erroneously expect the same characteristics during construction and the same performance during hot and cold weather conditions.

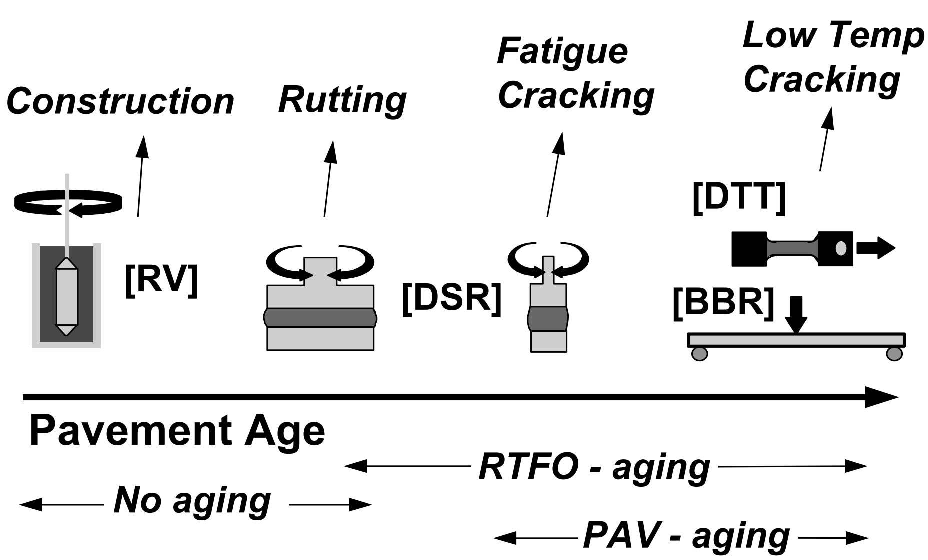


SUPERPAVE BINDER PROPERTY MEASUREMENTS

The new Superpave binder tests measure physical properties that can be related directly to field performance by engineering principles. Each of these new tests will be described in detail later in this text. At this point in the course, the key detail is that the Superpave tests characterize asphalt at a wide range of temperatures and ages. Superpave characterizes them at the actual pavement temperatures that they will experience, and at the periods of time when the asphalt distresses are most likely to occur.

Superpave Binder Test	Purpose
Dynamic Shear Rheometer (DSR)	Measure properties at high and intermediate temperatures
Rotational Viscometer (RV)	Measure properties at high temperatures
Bending Beam Rheometer (BBR) Direct Tension Tester (DTT)	Measure properties at low temperatures
Rolling Thin Film Oven (RTFO) Pressure Aging Vessel (PAV)	Simulate hardening (durability) characteristics





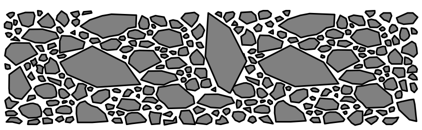
MINERAL AGGREGATE BEHAVIOR

A wide variety of mineral aggregates have been used to produce HMA. Some materials are referred to as *natural* aggregate because they are simply mined from river or glacial deposits and are used without further processing to manufacture HMA. These are often called "bank-run" or "pit-run" materials. *Processed* aggregate can include natural aggregate that has been separated into distinct size fractions, washed, crushed, or otherwise treated to enhance certain performance characteristics of the finished HMA. In most cases, the main processing consists of crushing and sizing.

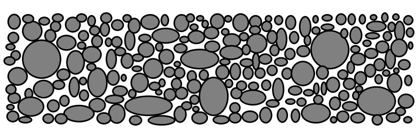
Synthetic aggregate consists of any material that is not mined or quarried and in many cases represents an industrial by-product. Blast furnace slag is one example. Occasionally, a synthetic aggregate will be produced to impart a desired performance characteristic to the HMA. For example, light-weight expanded clay or shale is sometimes used as a component to improve the skid resistance properties of HMA.

An existing pavement can be removed and reprocessed to produce new HMA. Reclaimed asphalt pavement or "RAP" is a growing and important source of aggregate for asphalt pavements.

Increasingly, waste products are used as aggregate or otherwise disposed of in asphalt pavements. Scrap tires and glass are the two most well known waste products that have been successfully "landfilled" in asphalt pavements. In some cases, waste products can actually be used to enhance certain performance characteristics of HMA. In other cases, it is considered sufficient that a solid waste disposal problem has been solved and no performance enhancing benefit from the waste material is expected. However, it is hoped that performance will not be sacrificed simply to eliminate a solid waste material.



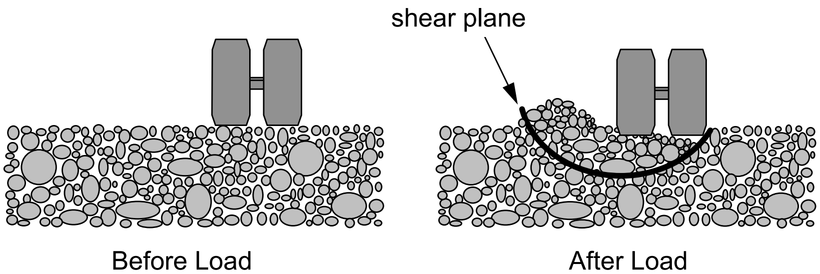
Cubical Aggregate



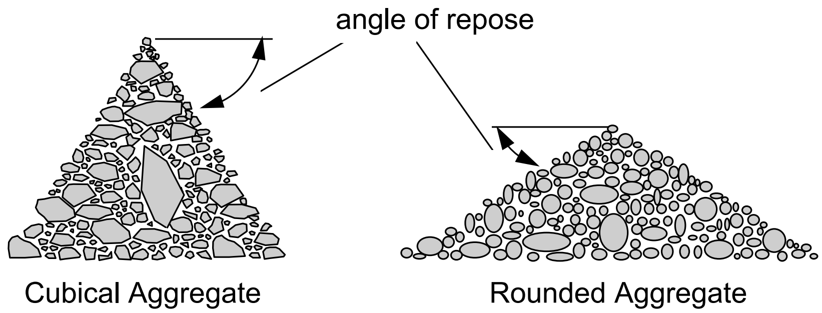
Rounded Aggregate

Regardless of the source, processing method, or mineralogy, aggregate is expected to provide a strong, stone skeleton to resist repeated load applications. Cubical, rough-textured aggregates provide more strength than rounded, smooth-textured aggregates Even though a cubical piece and rounded piece of aggregate may possess the same inherent strength, cubical aggregate particles tend to lock together resulting in a stronger mass of material. Instead of locking together, rounded aggregate particles tend to slide by each other.

When a mass of aggregate is loaded, there may occur within the mass a plane where aggregate particles begin to slide by or "shear" with respect to each other, which results in permanent deformation of the mass. It is at this plane where the "shear stress" exceeds the "shear strength" of the aggregate mass. Aggregate shear strength is of critical importance in HMA.



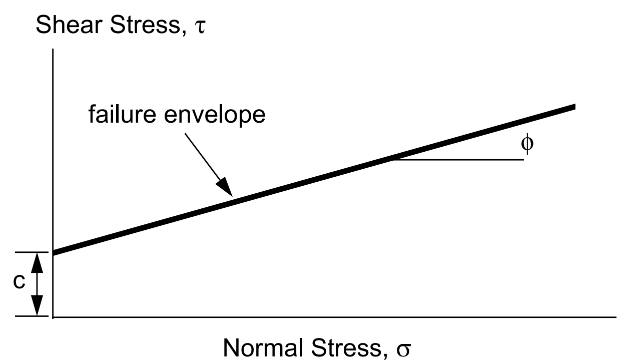
Contrasting aggregate shear strength behavior can easily be observed in aggregate stockpiles since crushed (i.e., mostly cubical) aggregates form steeper, more stable piles than rounded aggregates. The slope on stockpiles is the angle of repose. The angle of repose of a crushed aggregate stockpile is greater than that of an uncrushed aggregate stockpile.



Engineers explain the shearing behavior of aggregates and other materials using Mohr-Coulomb theory, named after the individuals who originated the concept. This theory declares that the shear strength of an aggregate mixture is dependent on how well the aggregate particles hold together in a mass (often called cohesion), the stress the aggregates may be under, and the internal friction of the aggregate. The Mohr-Coulomb equation used to express the shear strength of a material is:

$$\tau = c + \sigma \times \tan \phi$$

where, τ = shear strength of aggregate mixture,
c = cohesion of aggregate,
σ = normal stress to which the aggregate is subjected
ϕ = angle of internal friction.



A mass of aggregate has relatively little cohesion. Thus, the shear strength is primarily dependent on the resistance to movement provided by the aggregates. In addition, when loaded, the mass of aggregate tends to be stronger because the resulting stress tends to hold the aggregate more tightly together. In other words, shear strength is increased. The angle of internal friction indicates the ability of aggregate to interlock, and thus, create a mass of aggregate that is almost as strong as the individual pieces.

To ensure a strong aggregate blend for HMA, engineers typically have specified aggregate properties that enhance the internal friction portion of the overall shear strength. Normally, this is accomplished by specifying a certain percentage of crushed faces for the coarse portion of an aggregate blend. Because natural sands tend to be rounded, with poor internal friction, the amount of natural sand in a blend is often limited.

SUPERPAVE MINERAL AGGREGATE PROPERTY MEASUREMENTS

During the SHRP research, pavement experts were surveyed to ascertain which aggregate properties were most important. There was general agreement that aggregate properties played a central role in overcoming permanent deformation. Fatigue cracking and low temperature cracking were less affected by aggregate characteristics. SHRP researchers relied on the experience of these experts and their own to identify two categories of aggregate properties that needed to be used in the Superpave system: consensus properties and source properties. In addition, a new way of specifying aggregate gradation was developed. It is called the design aggregate structure.

Consensus Properties

It was the consensus of the pavement experts that certain aggregate characteristics were critical and needed to be achieved in all cases to arrive at well performing HMA. These characteristics were called "consensus properties" because there was wide agreement in their use and specified values. Those properties are:

- coarse aggregate angularity,
- fine aggregate angularity,
- flat, elongated particles, and
- clay content.

There are required standards for these aggregate properties. The consensus standards are not uniform. They are based on traffic level and position within the pavement structure. Materials near the pavement surface subjected to high traffic levels require more stringent consensus standards. They are applied to a proposed aggregate blend rather than individual components. However, many agencies currently apply such requirements to individual aggregates so undesirable components can be identified. Each of these consensus property tests will be described in detail later in this text.

Source Properties

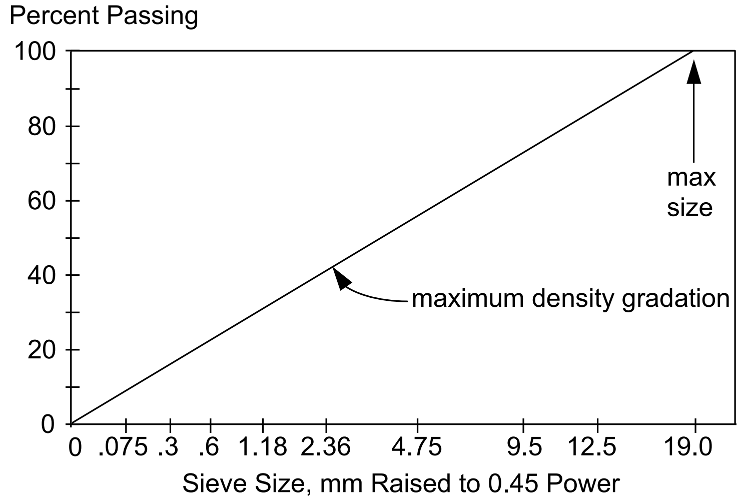
In addition to the consensus aggregate properties, pavement experts believed that certain other aggregate characteristics were critical. However, critical values of these properties could not be reached by consensus because needed values were source specific. Consequently, a set of "source properties" was recommended. Specified values are established by local agencies. While these properties are relevant during the mix design process, they may also be used as source acceptance control. Those properties are:

- toughness,
- soundness, and
- deleterious materials

Gradation

To specify gradation, Superpave uses a modification of an approach already used by some agencies. It uses the 0.45 power gradation chart to define a permissible gradation. An important feature of the 0.45 power chart is the maximum density gradation. This gradation plots as a straight line from the maximum aggregate size through the origin. Superpave uses a standard set of ASTM sieves and the following definitions with respect to aggregate size:

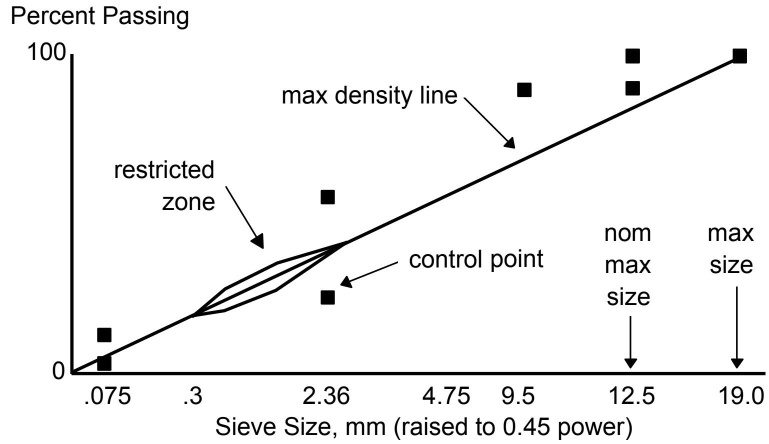
- Maximum Size: One sieve size larger than the nominal maximum size.
- Nominal Maximum Size: One sieve size larger than the first sieve to retain more than 10 percent.



The maximum density gradation represents a gradation in which the aggregate particles fit together in their densest possible arrangement. Clearly this is a gradation to avoid because there would be very little aggregate space within which to develop sufficiently thick asphalt films for a durable mixture. Shown is a 0.45 power gradation chart with a maximum density gradation for a 19 mm maximum aggregate size and 12.5 mm nominal maximum size.

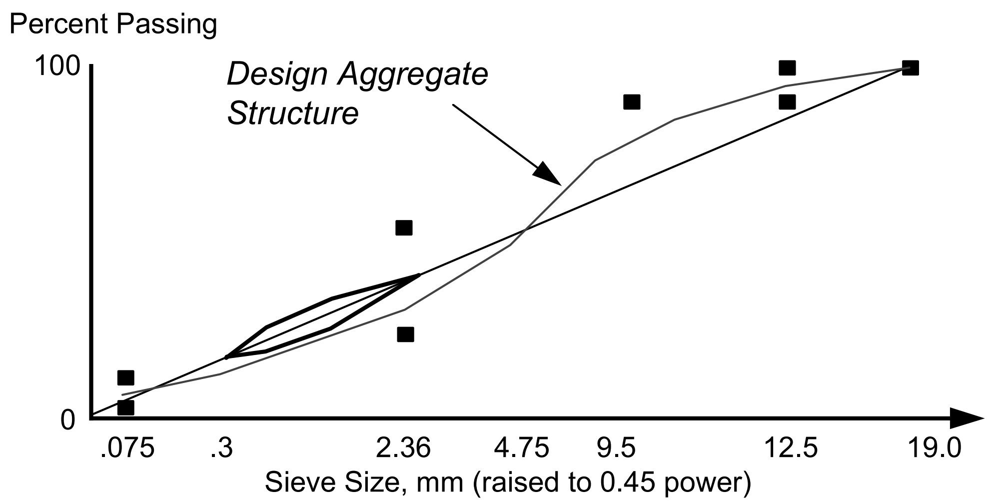
To specify aggregate gradation, two additional features are added to the 0.45 power chart: control points and a restricted zone. Control points function as master ranges through which gradations must pass. They are placed on the nominal maximum size, an intermediate size (2.36 mm), and the dust size (0.075 mm). Illustrated are the control points and restricted zone for a 12.5 mm Superpave mixture.

The restricted zone resides along the maximum density gradation between the intermediate size (either 4.75 or 2.36 mm) and the 0.3 mm size. It forms a band through which gradations should not pass. Gradations that pass through the restricted zone have often been called "humped gradations" because of the characteristic hump in the grading curve that passes through the restricted zone. In most cases, a humped gradation indicates a mixture that possesses too much fine sand in relation to total sand. This gradation practically always results in tender mix behavior, which is manifested by a mixture that is difficult to compact during construction and offers reduced resistance to permanent deformation during its performance life. Gradations that violate the restricted zone may possess weak aggregate skeletons that depend too much on asphalt binder stiffness to achieve mixture shear strength. These mixtures are also very sensitive to asphalt content and can easily become plastic.



The term used to describe the cumulative frequency distribution of aggregate particle sizes is the *design aggregate structure*. A design aggregate structure that lies between the control points and avoids the restricted zone meets the requirements of Superpave with respect to gradation. Superpave defines five mixture types as defined by their nominal maximum aggregate size:

Superpave Mixtures		
Superpave Mixture Designation	Nominal Maximum Size, mm	Maximum Size, mm
37.5 mm	37.5	50
25 mm	25	37.5
19 mm	19	25
12.5 mm	12.5	19
9.5 mm	9.5	12.5



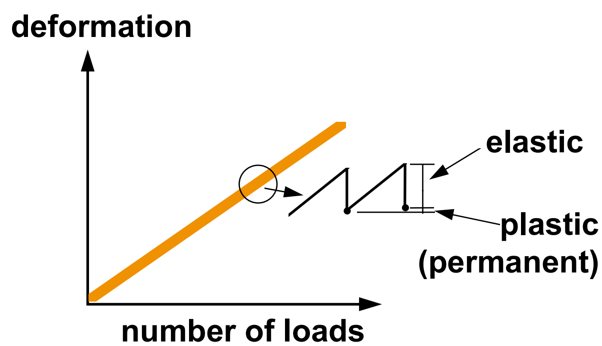
ASPHALT MIXTURE BEHAVIOR

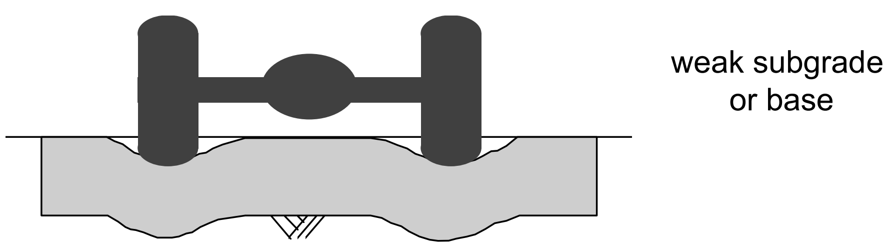
When a wheel load is applied to a pavement, two stresses are transmitted to the HMA: vertical compressive stress within the asphalt layer, and horizontal tensile stress at the bottom of the asphalt layer. The HMA must be internally strong and resilient to resist the compressive stresses and prevent permanent deformation within the mixture. In the same manner, the material must also have enough tensile strength to withstand the tensile stresses at the base of the asphalt layer, and also be resilient to withstand many load applications without fatigue cracking. The asphalt mixture must also resist the stresses imparted by rapidly decreasing temperatures and extremely cold temperatures.

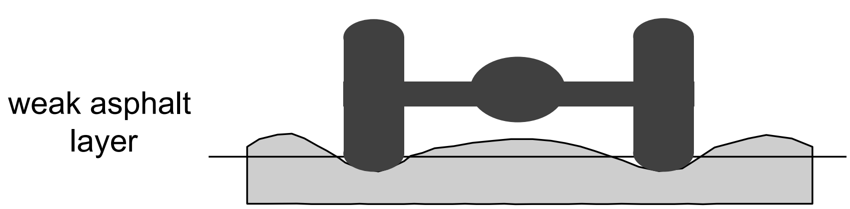
While the individual properties of HMA components are important, asphalt mixture behavior is best explained by considering asphalt cement and mineral aggregate acting together. One way to understand asphalt mixture behavior is to consider the primary asphalt pavement distress types that engineers try to avoid: permanent deformation, fatigue cracking, and low temperature cracking. These are the distresses analyzed in Superpave.

Permanent Deformation

Permanent deformation is the distress that is characterized by a surface cross section that is no longer in its design position. It is called "permanent" deformation because it represents an accumulation of small amounts of deformation that occurs each time a load is applied. This deformation cannot be recovered. Wheel path rutting is the most common form of permanent deformation. While rutting can have many sources (e.g., underlying HMA weakened by moisture damage, abrasion, and traffic densification), it has two principal causes.





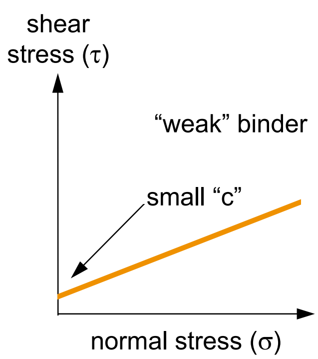


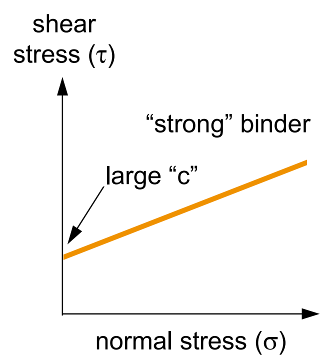
In one case, the rutting is caused by too much repeated stress being applied to the subgrade (or subbase or base) below the asphalt layer. Although stiffer paving materials will partially reduce this type of rutting, it is normally considered more of a structural problem rather than a materials problem. Essentially, there is not enough pavement strength or thickness to reduce the applied stresses to a tolerable level. A pavement layer that has been unexpectedly weakened by the intrusion of moisture may also cause it. The deformation occurs in the underlying layers rather than in the asphalt layers.

The type of rutting of most concern to asphalt designers is deformation in the asphalt layers. This rutting results from an asphalt mixture without enough shear strength to resist the repeated heavy loads. A weak mixture will accumulate small, but permanent, deformations with each truck pass, eventually forming a rut characterized by a downward and lateral movement of the mixture. The rutting may occur in the asphalt surface course, or the rutting that shows on the surface may be caused to a weak underlying asphalt course.

Rutting of a weak asphalt mixture typically occurs during the summer under higher pavement temperatures. While this might suggest that rutting is solely an asphalt cement problem, it is more correct to address rutting by considering the mineral aggregate and asphalt cement. In fact, the previously described Mohr-Coulomb equation ($\tau = c + \sigma \times \tan \phi$) can again be used to illustrate how both materials can affect rutting.

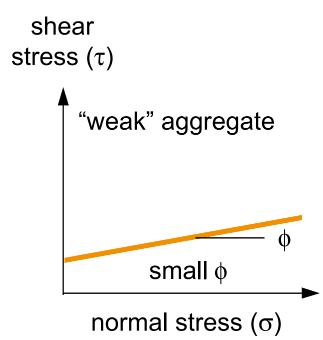
$$\underbrace{\tau}_{\textbf{shear strength}} = \underbrace{c}_{\textbf{asphalt binder contribution}} + \underbrace{\sigma}_{\textbf{normal stress}}(\tan \underbrace{\phi}_{\textbf{aggregate contribution}})$$

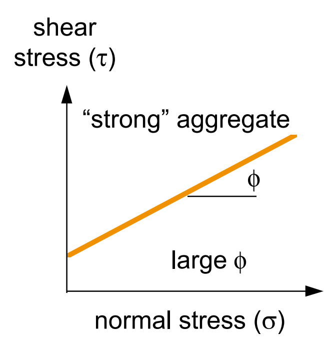




In this case, τ is considered the shear strength of the asphalt mixture. The cohesion (c) can be considered the portion of the overall mixture shear strength provided by the asphalt cement. Because rutting is an accumulation of very small permanent deformations, one way to ensure that asphalt cement provides its "fair share" of shear strength is to use an asphalt cement that is not only stiffer but also behaves more like an elastic solid at high pavement temperatures. That way, when a load is applied to the asphalt cement in the mixture, it tends to act more like a rubber band and spring back to its original position rather than stay deformed.

Another way to increase the shear strength of an asphalt mixture is by selecting an aggregate that has a high degree of internal friction (ϕ). This is accomplished by selecting an aggregate that is cubical, has a rough surface texture, and graded in a manner to develop particle-to-particle contact. When a load is applied to the aggregate in the mixture, the aggregate particles lock tightly together and function not merely as a mass of individual particles, but more as a *large, single, elastic stone*. As with the asphalt cement, the aggregate will act like a rubber band and spring back to its original shape when unloaded. In that



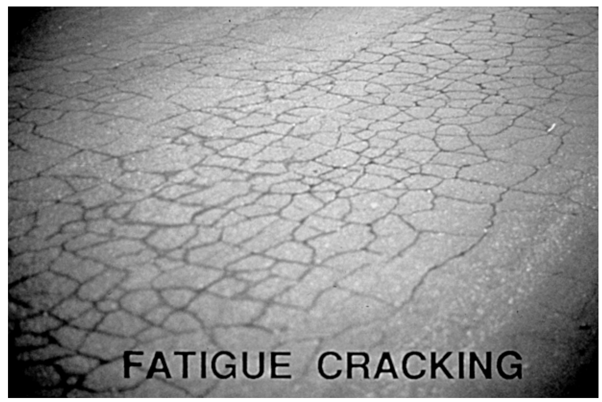


way, no permanent deformation accumulates.
While it is obvious that the largest portion of the resistance to permanent deformation of the mixture is provided by the aggregate, the portion provided by the asphalt binder is very important. Binders that have low shear characteristics due to composition or temperature minimize cohesion and to a certain extent, the confining "normal" stress. Thus the mixture begins to behave more like an unbound aggregate mass.

Fatigue Cracking

Fatigue cracking occurs when the applied loads overstress the asphalt materials, causing cracks to form. An early sign of fatigue cracking consists of intermittent longitudinal cracks in the traffic wheel path. Fatigue cracking is progressive because at some point the initial cracks will join, causing even more cracks to form. An advanced stage of fatigue cracking is called alligator cracking, characterized by transverse cracks joining the longitudinal cracks. In extreme cases, a pothole forms when pavement pieces become dislodged by traffic.

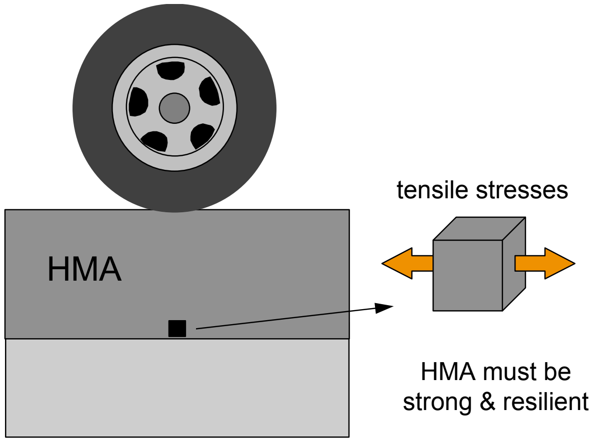
Fatigue cracking is usually caused by a number of factors occurring simultaneously. Obviously, repeated heavy loads must be present. Thin pavements or those with weak underlying layers are prone to high deflections under heavy wheel loads. High deflections increase the horizontal tensile stresses at the bottom of the asphalt layer, leading to fatigue cracking. Poor drainage, poor construction, and/or an underdesigned pavement can contribute to this problem.



Often, fatigue cracking is merely a sign that a pavement has received the design number of load applications, in which case the pavement is simply in need of planned rehabilitation. Assuming that the fatigue cracking occurs at the end of the design period, it would be considered a natural progression of the pavement design strategy. If the observed cracking occurs much sooner than the design period, it may be a sign that traffic loads were underestimated.

Consequently, the best ways to overcome fatigue cracking are:

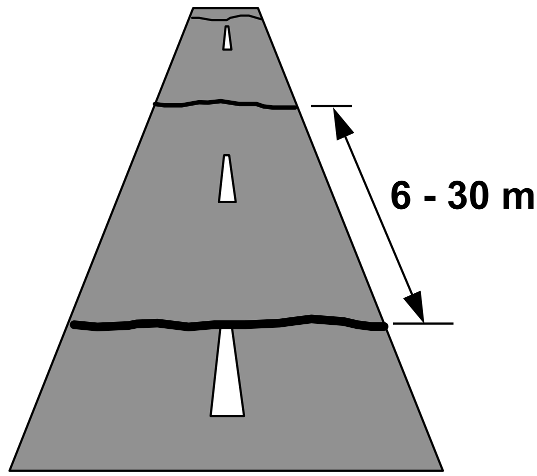
- adequately account for the anticipated number of heavy loads during design,
- keep the subgrade dry using whatever means available,
- use thicker pavements,
- use paving materials that are not excessively weakened in the presence of moisture, and
- use paving materials that are resilient enough to withstand normal deflections.



Only the last item, selection of resilient materials, can be strictly addressed using materials selection and design. As a load is applied, horizontal tensile stresses occur near the bottom of an asphalt layer. The HMA must have enough tensile strength to withstand the applied tensile stress, and be resilient enough to withstand repeated load applications without cracking. Thus, HMA must be designed to behave like a soft elastic material when loaded in tension to overcome fatigue cracking. This is accomplished by placing an upper limit on the asphalt cement's stiffness properties, since the tensile behavior of HMA is strongly influenced by the asphalt cement. In effect, soft asphalts have better fatigue properties than hard asphalts.

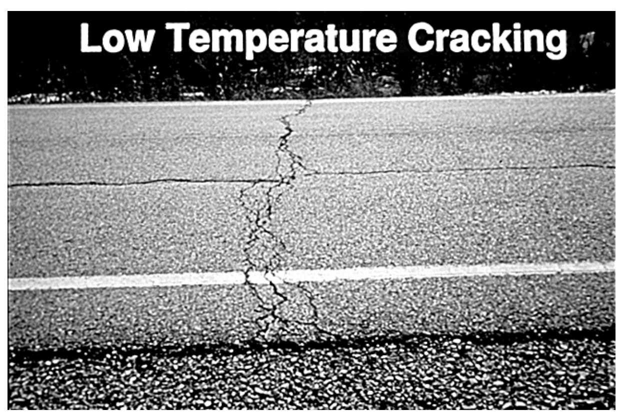
Low Temperature Cracking

Low temperature cracking is caused by adverse environmental conditions rather than by applied traffic loads. It is characterized by intermittent transverse cracks that occur at a surprisingly consistent spacing.



Low temperature cracks form when an asphalt pavement layer shrinks in cold weather. As the pavement shrinks, tensile stresses build within the layer. At some point along the pavement, the tensile stress exceeds the tensile strength and the asphalt layer cracks. Low temperature cracks occur primarily from a single cycle of low temperature, but can develop from repeated low temperature cycles.

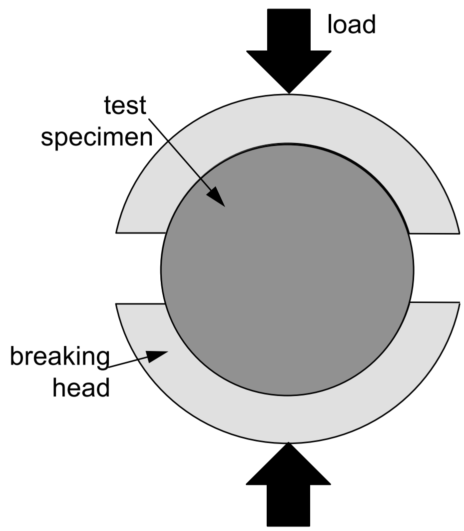
The asphalt binder plays the key role in low temperature cracking. In general, hard asphalt binders are more prone to low temperature cracking than soft asphalt binders. Asphalt binders that are excessively aged, because they are unduly prone to oxidation and/or contained in a mixture constructed with too many air voids, are more prone to low temperature cracking. Thus, to overcome low temperature cracking engineers must use a soft binder that is not overly prone to aging, and control in-place air void content and pavement density so that the binder does not become excessively oxidized.

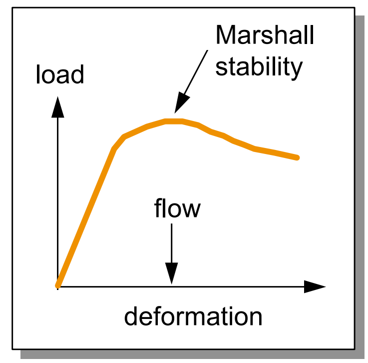


PRE-SUPERPAVE ASPHALT MIXTURE DESIGN PROCEDURES

Most agencies currently use the Marshall mix design method. It is by far the most common procedure used in the world to design HMA. Developed by Bruce Marshall of the Mississippi State Highway Department, the U.S. Army Corps of Engineers refined and added certain features to Marshall's approach and it was formalized as ASTM D 1559, *Resistance to Plastic Flow of Bituminous Mixtures Using the Marshall Apparatus* (AASHTO T 245). The Marshall method entails a laboratory experiment aimed at developing a suitable asphalt mixture using stability/flow and density/voids analyses.

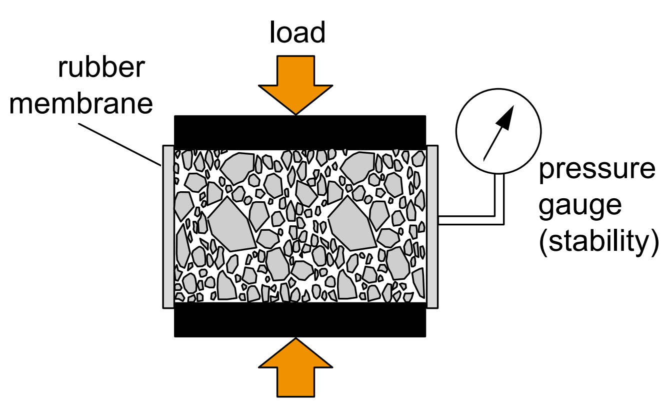
One of the strengths of the Marshall method is its attention to density and voids properties of asphalt materials. This analysis ensures the proper volumetric proportions of mixture materials for achieving a durable HMA. Another advantage is that the required equipment is relatively inexpensive and portable, and thus, lends itself to remote quality control operations. Unfortunately, many engineers believe that the impact compaction used with the Marshall method does not simulate mixture densification as it occurs in a real pavement. Furthermore, Marshall stability does not adequately estimate the shear strength of HMA. These two situations make it difficult to assure the rutting resistance of the designed mixture. Consequently, asphalt technologists agree that the Marshall method has outlived its usefulness for modern asphalt mixture design.





Francis Hveem of the California Department of Transportation developed the Hveem mix design procedure. Hveem and others refined the procedure, which is detailed in ASTM D 1560, *Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus*, (AASHTO T246) and ASTM D 1561, *Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor* (AASHTO T247). The Hveem method is not commonly used for HMA outside the western United States.

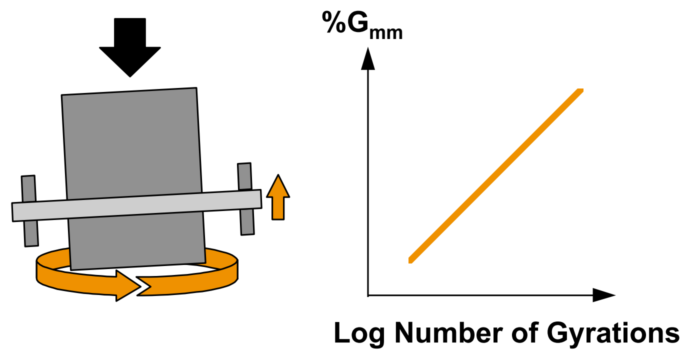
The Hveem method also entails a density/voids and stability analysis. The mixture's resistance to swell in the presence of water is also determined. The Hveem method has two primary advantages. First, the kneading method of laboratory compaction is thought to better simulate the densification characteristics of HMA in a real pavement. Second, Hveem stability is a direct measurement of the internal friction component of shear strength. It measures the ability of a test specimen to resist lateral displacement from application of a vertical load.



A disadvantage of the Hveem procedure is that the testing equipment is somewhat expensive and not very portable. Furthermore, some important mixture volumetric properties that are related to mix durability are not routinely determined as part of the Hveem procedure. Some engineers believe that the method of selecting asphalt content in the Hveem method is too subjective and may result in non-durable HMA with too little asphalt.

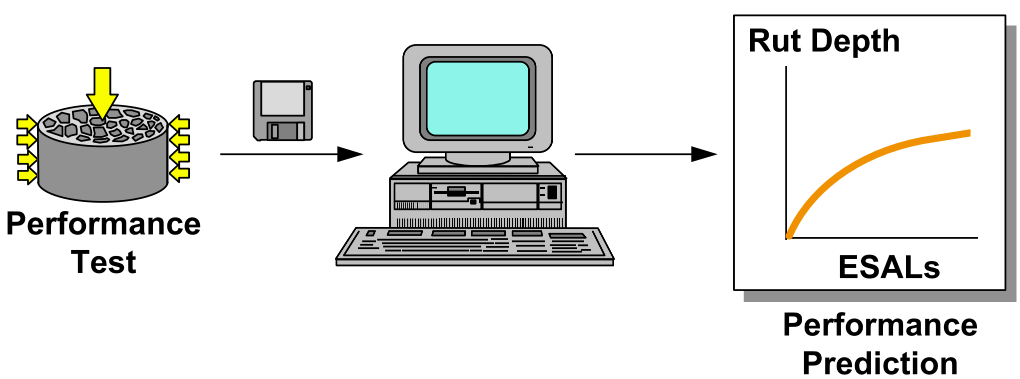
SUPERPAVE ASPHALT MIXTURE DESIGN

Key features in the Superpave system are laboratory compaction and testing for mechanical properties. Laboratory compaction is accomplished by means of a Superpave Gyratory Compactor (SGC). While this device shares some common traits with the Texas gyratory compactor, it is a completely new device with new operational characteristics. Its main utility is to fabricate test specimens. However, by capturing data during SGC compaction, a mix design engineer can also gain insight into the compactability of HMA. The SGC can help avoid mixtures that exhibit tender mix behavior or densify to dangerously low air void contents under the long-term action of traffic.



The performance of HMA immediately after construction is influenced by mixture properties that result after hot mixing and compaction. Consequently, incorporated into the Superpave system is a short term aging protocol that required the loose mixture to be oven aged for two hours at the mixture's specified compaction temperature prior to compaction in the SGC.

The SHRP asphalt research program also developed a number of HMA performance prediction tests. Output from these tests will eventually be used to make detailed predictions of pavement performance. In other words, test procedures and the final performance prediction models will allow an engineer to estimate the performance life of a prospective HMA in terms of equivalent axle loads (ESALs) or time to achieve a certain level of rutting, fatigue cracking, and low temperature cracking. This integrated mixture and structural analysis system will allow the designer to evaluate and compare the costs associated with using various materials and applications.



Two new sophisticated testing devices were developed: the Superpave Shear Tester (SST) and Indirect Tensile Tester (IDT). The test output from these devices can provide direct indications of mix behavior, or will eventually generate input to performance prediction models.

Using the mechanical properties of the HMA and these performance prediction models, mix design engineers will be able to estimate the combined effect of asphalt binders, aggregates, and mixture proportions. The models will take into account the structure, condition, and properties of the existing pavement (if applicable) and the amount of traffic to which the proposed mixture will be subjected over its performance life. The output of the models will be millimeters of rutting, percent area of fatigue cracking, and spacing (in meters) of low temperature cracks. By using this approach, the Superpave system will become the ultimate design procedure by linking material properties with pavement structural properties to predict actual pavement performance. When the pavement modeling is completed, the benefit (or detriment) of new materials, different mix designs, asphalt modifiers, and other products can be quantified in terms of cost versus predicted performance. This capability would reduce the dependency on field test sections for relative comparisons.